Widening of the electron avalanche in a barrier discharge due to the photoemission

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The evolution of the narrow electron avalanche in a barrier discharge is studied via two-dimensional fluid model. If the photoemission is taken into account as a primary source of electrons at the cathode, the electron avalanche initiates a quasi-homogeneous glow discharge. This discharge is about 10 ns in duration; it covers all the electrode area.

1. Introduction

One of the methods to produce homogeneous glow plasma at atmospheric pressure is to use the barrier discharge. In most common gases, such as N_2 or air, as the barriers are made of glass or Al_2O_3, only Townsend discharge is homogeneous [1]. The reason is that this discharge mode is stable relative to radial fluctuations in distinction with the glow mode [2].
However, there is a way to produce homogeneous glow discharge in N_2 at low (50 Hz) frequency by using electret "Mylar" barriers [1]. A possible mechanism of its initiation is the subject of the present work.

2. Source of initial electrons in a DBD

The experimental profile of current in Townsend discharge [1] can be obtained in a model if desorption is assumed to be the primary source of electrons at the cathode [3]. At 50 Hz, low value of dU/dt does not allow to obtain the glow mode in presence of the desorption. The charge transfer causes the screening of the slowly growing external voltage, and the overvoltage necessary for the development of a glow mode cannot be obtained. This overvoltage can occur if no electrons are emitted from the cathode. Absence of charge loss is the feature of electrets, so this mechanism is probable in the case of Mylar barriers. After the overvoltage is obtained, any incident electron may initiate the breakdown. The remarkable widening of a resulting avalanche can be caused only by the photoemission.

3. Model

The model is based on 2D fluid equations for electrons and ions as well as Poisson equation. Following [3], only direct ionization is taken into account. The photoemission is introduced in accordance with [4].

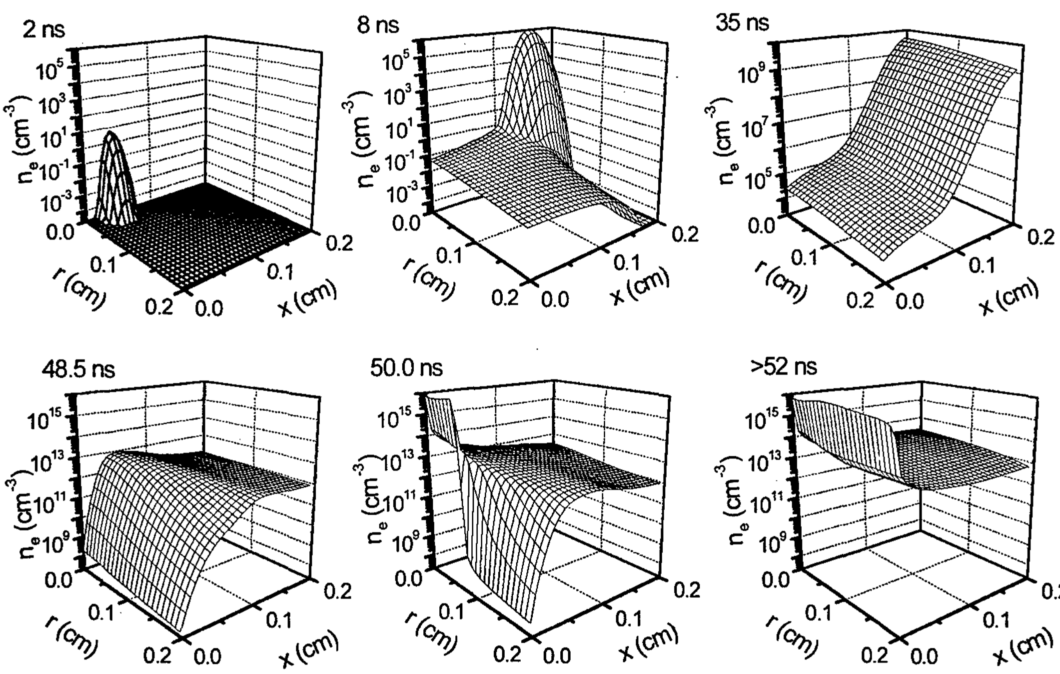

Fig. 1. Electron density distribution in different phases of the breakdown.

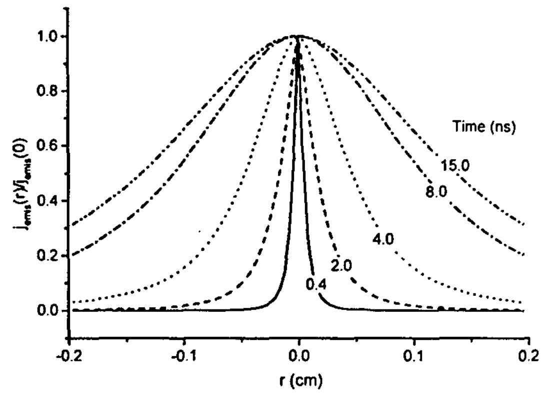

Fig. 2. Profile of emission current in different phases.

The system is solved numerically for the discharge geometry similar to [1], i.e., gap width 0.2 cm, barrier width 0.35 cm, ε=3.3. The discharge radius is chosen to be 0.5 cm. The working gas is nitrogen. The external voltage is equal to 13 kV.
The initial electron density is chosen to have Gaussian profile both in radial and axial directions (Δx=Δr=0.005 cm). The maximum is at x=r=0; its value is 1 cm^{-3}.

4. Results and discussion

In figure 1 one can see different stages of breakdown. First stage is the drift of the initial avalanche towards the anode (t<10 ns) and its growth due to the ionization. Since the overvoltage is not very high, the charged particle density in the avalanche does not achieve the value necessary for the formation of a streamer ($n \sim 10^{12}$ cm^{-3}). Therefore, after the initial avalanche reaches the anode (t≈15 ns), it is adsorbed.
The UV photons produced by fast electrons in the avalanche hit the cathode and cause the photoemission. The essential widening of the electron density due to this process can be seen in figure 1 for t = 8 ns. This widening is illustrated by figure 2, where the emission current is shown in different discharge phases.
The external voltage is chosen so as

$$\exp(\alpha L) > \frac{1}{\gamma_{eff}}, \qquad (1)$$

where α is the Townsend ionization coefficient and γ_{eff} is the effective secondary emission coefficient (in the case of photoemission $\gamma_{eff} = \gamma_{ph} / 2$). Therefore, the electron density grows in time due to this overvoltage even after the disappearance of the initial avalanche. The Townsend phase of the discharge can be observed in figure 1 at t=35 ns.
After the electron density at the anode attains the critical value, a streamer front is formed. This front runs rapidly in the cathode direction (Figure 1, t=48.5 ns).
Since the electron density was maximal at r=0, the streamer front near the axis of symmetry reaches the cathode earlier (cf. the instability of the streamer front [2]). At t=50.0 ns the streamer front reaches the cathode

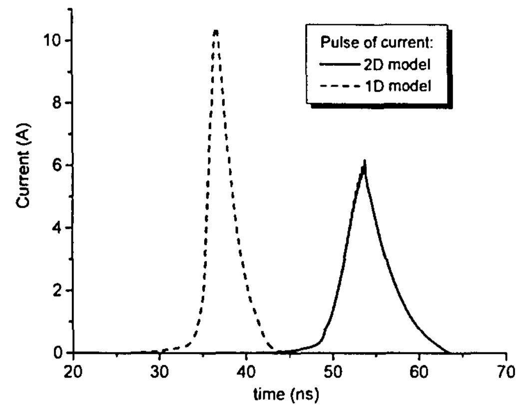

Fig. 3. External current pulse in 2D and 1D models.

for r < 0.1 cm and do not for larger radii.
At t > 55 ns one can see the final stage of the breakdown. The electron density attains its maximal value in all radial points, and the current becomes to decrease (see also figure 3).
The effect of delay of the streamer front for remote radial points causes the widening of the current peak in comparison with that without delay (1D model). The difference in current pulses is seen in figure 3. Larger electrode area may lead to even stronger widening of the current peak up to some tens of nanoseconds.

5. Conclusion

It is shown that, in presence of the photoemission and in absence of any other emission processes, even one incident electron may cause a quasi-homogeneous glow discharge covering all the electrode area. At low frequencies, this effect may be the origin of the homogeneous glow barrier discharge.
The delay of the streamer front far from the position of the initial avalanche may cause the increase of the duration of the current pulse.

6. Acknowledgements

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